

Chapter 3 Basin Design and Operation Criteria

3-1. Basin Design Criteria

a. Harbor function. The function that a harbor is to provide will determine its design requirements. Sembler et al. (1969) categorize harbors according to the following functions: harbors of refuge, commercial, fishing boat moorage, convenience harbor, recreational center, and yacht club.

(1) Harbor of refuge. When a remote harbor is provided specifically to accommodate transient small boats rather than as a home port for the local boats of the immediate area, it is designated as a harbor of refuge. Such harbors need not have all the refinements of a home port, but must have an entrance that is navigable in adverse weather, access to emergency aid, and appropriate facilities to accommodate the transient boater. Depending on the class of boat and characteristics of the region, the safe cruising distance for small boats is usually between 20 and 40 miles, or two hours cruising time. In remote areas, harbors of refuge meeting just the needs of the transient boaters often are subsidized. In these instances, the harbor of refuge may possibly be made self-sustaining by berthing a small number of home-based boats in addition to meeting the periodic needs of transient boats; it may not survive economically on either type of boat alone.

(2) Commercial. Small boat harbors are designed for various commercial fishing fleets, barges, and small boat transportation terminals, including berths for excursion craft of various kinds. Small boat facilities are often within or adjacent to harbors built primarily for deep-draft cargo or passenger vessels. In such cases, large ships and small craft will move through the same waters. Planning criteria must be adopted to reduce the collision hazard to a minimum without curtailing the activities of either class more than is essential for navigational safety (Dunham and Finn 1974).

(3) Commercial fishing boat moorage. Harbors for commercial fishing boats may be considered a special type of installation. This is due largely to the type of usage, the characteristics and habits of commercial fishery, and equipment requirements. Because a fishing boat is a work boat and the operator's work in port is essentially preparation for the next trip, utility usually supercedes appearance.

(4) Convenience harbor. The convenience harbor is generally designed as an enroute stopover point and provides a minimum of services. Such harbors may serve for overnight stays, temporary tie-ups for repairs and obtaining supplies, and similar usages. Facilities of this type should generally be located at or near population centers for availability of food, fuel, and amusement. Some degree of harbor protection is necessary, but moorage facilities can be minimal and services limited. Because of the lack of direct revenue from a harbor of this type, it is anticipated that it would be installed at community expense with few, if any, charges, its benefit to the community coming from other business generated.

(5) Recreational. Small boat harbors are designed for various recreational craft, including: sailboats, rowboats, pedal craft, and air-cushion vehicles. Other exotic craft are not specifically covered, although the basin and entrance design techniques described will be found satisfactory for all classes of small boat. The development of a recreational harbor will require not only the best weather protection, but also waterside and landside facilities that are best suited for its function. Boaters may patronize a deluxe restaurant, a pleasant bar, and various concessions. They may support boat sales, boat repair facilities, a marine supply store, clothing shops, and other similar establishments. They may use facilities for dancing, skating, bathing, skin diving, and water-skiing, if available. However, they usually demand the most in conveniences, utilities, and services, and a well-managed, clean, and attractive marina.

(6) Yacht clubs. In many areas, boating enthusiasts group together into yacht clubs. These are usually, by their nature, private installations accessible to members only. Yacht clubs may be somewhat meager in their facilities and appointments or may be quite lavish. Of prime importance will be a clubhouse at the water's edge with a good dining room and bar, and an assembly place for races and regattas. These races and regattas constitute one of the major interests in boating of a large segment of small boat owners. These are classed as amateur sports and can be sponsored only by a recognized yacht club. On this basis, the yacht club performs a desirable function and one or more of these should be considered in the planning and design of any recreational type of small boat harbor.

b. Site selection.

(1) Site selection for a small boat basin is probably the single most important aspect of developing a marina in an

environmentally sound manner. A site selected to complement the marina concept and to permit maximum use of the natural attributes can facilitate the entire development process from permit application through completion of construction. For example, wetlands and island refuges may be developed through the construction process.

(2) Selection of a site that has favorable hydrographic characteristics and requires the least amount of modification can reduce potential impacts. Any future modification or expansion should be considered in the design phase. One method is to set a basin perimeter when the basin is constructed. Thereafter, modifications that occur within that perimeter (such as dock reconfiguration) are considered not significant. Another method is to set a limit, such as a 25-percent increase in the number of slips or a set number of slips (such as an increase of more than five slips). The final method is a combination of the above methods.

(3) Small boat basins should not be located in or immediately adjacent to wetlands. In addition, development of small boat basins should not disrupt unique areas such as mouths of streams, isolated aquatic plant beds, or small areas with valuable rock/rubble substrate. These areas should be avoided, or at least small boat basin design and subsequent operation should be implemented to minimize disruption to these habitats. Suitable habitat evaluation techniques are available for wetlands (Adamus et al. 1988).

(4) Site selection considerations for recreational harbors are intended to ensure that a site provides usable land and water resources for marina operation. Chamberlain (1983) recommends that at a minimum, the land area should be at least 10 acres and above the local floodplain. The usable water area should be approximately equal to available land area. The site should offer protection from wave action in the adjacent body of water and at least some protection from wind. The water depth should not be less than 8 ft (2.4 m) at mean low water and not over 20 ft (6.1 m) at mean high water. Figure 3-1 illustrates desirable and undesirable site locations for boat basins.

(5) A major requirement in designing a small boat basin is that it be located and sized to accommodate present and future user needs and related harbor facilities. It must be located in adequate depths for safe vessel operation and be accessible to a nearby navigation channel. Alternative measures and sites for developing a small boat basin must be evaluated and compared for impacts on the

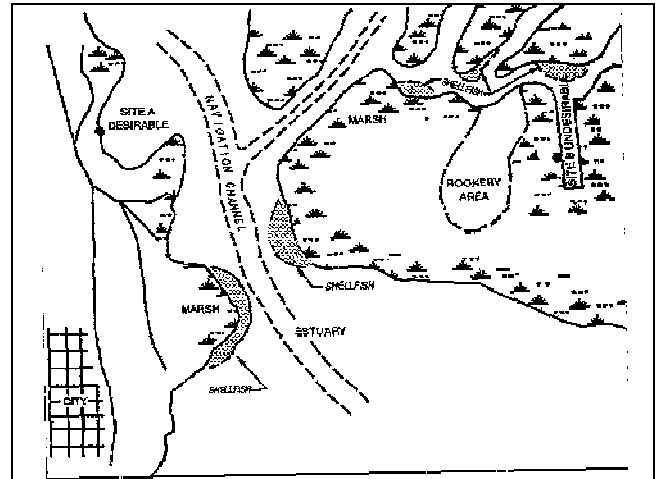


Figure 3-1. Desirable and undesirable site characteristics

natural environment, as mandated by the National Environmental Policy Act and other environmental Policy Act and other environmental statutes and guidelines.

(6) Physical factors that must be considered in locating a small boat basin are circulation and current patterns, bottom conditions, wave action, tides, sedimentation and shoaling, and prevailing winds (Brockwell 1987). If conditions are not suitable, major environmental problems may result. Hazardous conditions for small craft operating out of the basin because of waves, currents, and shoaling may be created. Water quality may be degraded if tides and currents are not adequate to flush the basins. The potential for flushing of marina waters should be the prime consideration in selecting a site. Sites on open

water or at the mouth of creeks and tributaries generally have higher flushing rates than those in coves and toward the head of creeks and tributaries that have lower flushing rates.

(7) Dredging and maintenance can also be minimized by selecting deep sites with low sediment transport potential. The land topography at inland sites should be suitable to provide protection to the boat basin from winds, tides, and river flow.

(8) A small boat basin should have the following site characteristics:

- (a) Easy access to open water.
- (b) Accessibility from roads and waterways.

- (c) Location in protected waters.
- (d) Location near navigable water.
- (e) Access to areas suitable for dredged material disposal.
- (f) High tides and flushing rates.
- (g) Compatibility with existing land and water uses.
- (h) Good water quality.
- (i) Absence of commercial shellfish beds.
- (j) Low value as a fish and wildlife habitat.
- (k) Absence of rare, threatened, or endangered species.

c. *Site conditions.* The natural elements of a site for constructing a small boat basin, such as local weather conditions, ice conditions, tides, currents, waves, and shoaling factors all have to be investigated.

(1) Weather factors. Weather factors such as precipitation, wind, and fog must be considered when evaluating a site.

(a) Precipitation. Maximum rainfall or snowfall present no serious problems for small boat basin operations, although all surface drainage measures have to be considered in marina planning. Drainage facilities have to be designed to be capable of draining or diverting a maximum amount of rainfall. In regions where snowfall is heavy, land-based structures must be designed to withstand these snow loads.

(b) Wind. The prevailing wind is a wind blowing from one general direction for a major portion of the year. Prevailing winds are not the strongest winds. Winds of greater intensity, which occur less frequently, come from other directions. A wind rose may be used to graphically represent the direction, frequency, and intensity of winds at a particular location over a period of time. Heavy wind may affect water levels in the marina basin, raising or lowering the water level. Land-based structures must be designed to withstand the unusually heavy forces. Heavy wind may generate waves or move sand located in dune areas which may shoal the basin or the entrance to the marina. Breakwaters are constructed to protect the entrance to the basin. Planting grass or construction of sand fences may be used to stabilize sand movement.

(c) Fog. Fog may be a serious navigational problem if it reduces visibility. Many marinas have occasional foggy conditions, and for this reason, channels in a small boat basin should be as straight as possible. In regions where fog is a problem, marker buoys and other channel-marking devices have to be installed.

(2) Ice.

(a) In northern climates ice is a serious problem in the operation of small boat basins. In areas with moving ice sheets, marinas must be located in protected areas, because these ice sheets may crush not only boats but also marine structures. Protection is provided by locating the entrance to the marina oriented away from the direction of the prevailing wind or current. This will encourage ice floes to move out of the marina during breakup. The marina should be located as close as possible to an industrial complex so that any available waste heat may be utilized. Although thin ice formation cannot damage boats, they are usually removed from the water during the winter, even in protected marinas. In protected marinas, thick, unbroken ice sheets forming around piles which support marina piers may lift these piles when the water rises, and thus bring the whole structure out of alignment. Repeated freezing and thawing may eventually jack piles completely out of the ground. In large natural basins, wind-driven ice floes may crash onto marine structures as the ice melts in spring, causing considerable damage to these structures.

(b) In Finland, small boat basins have been built with considerable success having piers and quays with a width of 1.5-3.0 m supported by wooden batter piles (Kivekas and Sarela 1985). Batter piles provide better stability in the foundation soil. When water fluctuates steadily, the ice attached to the shore (to a wall of a solid type construction or to a dense row of piles) will break easily at that location when the water changes level. However, in tidal zones, ice could easily build up on vertical surfaces of structures that are fixed on the bottom, thus creating a destabilizing buoyancy force or an additional load on the foundation.

(3) Waves.

(a) Natural phenomena such as waves may be caused by winds, tides, earthquakes, or by disturbances caused by moving vessels. A designer should be interested in waves produced by wind and moving vessels, since they have the most influence on site selection and basin design. Passing ships may generate waves which are sometimes

of greater length than wind waves. Small boat basins on rivers experience the passing of ships or barges that may generate damaging waves. The effect of waves will depend on the height of the wave generated and the distance between the ship and the project site. As a rule of thumb, it can be assumed that the wave height is equal to twice the amount of vessel squat. The wave height at the riverbank is then computed using refraction and diffraction techniques. The wave length is equal to approximately one third of the vessel length (EM 1110-2-1615). If ship-generated waves are considered to be the design wave, model tests or prototype measurements are needed to verify or adjust the predictions. Additional information on the possible impact of vessel wakes may be obtained from Camfield, Ray, and Eckert (1980).

(b) Marina sites need to be protected from adverse wave effects. Some sites may be protected by one or more islands which shield the entrance from waves. If the site does not have natural protection against wave action, breakwaters or other wave-dissipating devices are used at the entrance or inside the marina.

(4) Tides. Tides and tide-like effects (e.g., water level change in inland lakes and rivers due to spring and fall flood) often play an important role in water quality control. The current-producing exchange of water by water fluctuation action may be essential to the marine ecology and the prevention of stagnation conditions. Water circulation is an important component in marina design and can be accomplished by the effective use of the tidal prism of the water. In inland lakes and rivers, water fluctuates in a slower cycle, and although it occurs too slowly to produce substantial water exchange effects, these effects have to be taken into account for the design.

(5) Currents.

(a) Currents are essentially horizontal movement of the water. At coastal locations, currents or flow of tides or freshets moving at only a few tenths of a knot generally cause no serious problems to marina operations. However, in swiftly moving rivers (with a speed of several knots) where seasonal floods are expected, or in large open bodies of water, where wind-generated current may be damaging to the marina, marinas should be in protected locations, e.g., secluded inlets, bays or lagoons, or breakwaters must be installed. Apart from the possibility of direct interference with marina operation, currents may also present other adverse functional effects such as scouring, deposition of sediments, and increased erosion rates.

(b) Currents may cause changes in wave effects, and in the impact of ice and flotsam (floating debris), as well as hampering construction operations. In tidal estuaries, the current can be expected to reverse. The value of tidal current velocity for many locations around the world may be obtained from tables that are published annually by the National Oceanic and Atmospheric Administration (NOAA). Depending on location as well as importance and cost, current velocity measurements may be considered for the project (Coastal and Ocean Engineering 1990).

(6) Shoaling.

(a) A principal cause of shoaling at entrances to marina basins is littoral drift, which is mainly the result of wave and/or current action. Any structure that interferes with wave or current action would cause abnormalities in the wave or current pattern and could substantially affect the shoaling process. Dunham and Finn (1974) suggested the following example. If the unprotected approach channel is dredged through a beach into an inner basin, the wave impinging on either side at the mouth will be refracted in such a way as to cause changes in the wave pattern approaching the lips of the channel. If the approach of the prevailing waves is normal to the shore, the initial effect will be a movement of the littoral material from the lips inward along each flank of the channel, thus eroding the lips and shoaling the inner channel fed by material from the beach on either side of the entrance. Unless tidal currents are strong enough to maintain an opening against the forces tending to shoal the entrance, the channel will soon be blocked. Where the prevailing wave approach is oblique to the shoreline, sediments being transported along the shore by littoral currents will be interrupted at the channel opening near the updrift lip, and that lip will soon begin to accrete. As the wave-induced longshore current again begins to "feel" the shore downdrift of the channel mouth, it attempts to reacquire its sediment load. As a result, at the same rate as the updrift lip accretes, the channel mouth will migrate in the downdrift direction. In each of these cases, the forces of nature are attempting to re-establish the littoral balance that was present before the channel was excavated. The above example is an oversimplified version of an extremely complex process, and excludes consideration of the effects of sandbar formation, eddy currents, and tidal channel meandering (Coastal and Ocean Engineering 1990).

(b) The customary solution to entrance shoaling is the construction of jetties along each flank of the channel

from the lips of the mouth seaward beyond the breaking zone. The structural features of the jetties must be such that the materials will not be washed through or over the structure into the channel. A typical section of a sand-tight, rubble-mound jetty is shown in Figure 3-2. If the littoral transport from one direction predominates and the entrance is stabilized by jetties, accretion will occur along the updrift shore and erosion along the downdrift shore.

(c) The entrance to off-river marinas is often subject to shoaling because of sediment deposition in the quiet water area and to eddy currents that might be created by the entrance configuration and the flowing water in the river. Although shoaling cannot be prevented, it is often reduced by proper entrance design. For example, a flat area on the downstream lip of the entrance could be provided from which a dragline can excavate deposits from the bottom of the entrance channel and cast them into the river downstream of the entrance (Figure 3-3). The entrance must be kept as narrow as practical to permit such an operation, and a training dike at the upstream lip is helpful in reducing the deposits (Coastal and Ocean Engineering 1990).

d. Marina design.

(1) General. Design considerations for a marina may include boat slips, water supply, sanitation, structural integrity, and esthetics of structural/environmental compatibility.

(a) Boat slips. Slip sizes are determined by the size the boats intended to use them. Table 3-1 shows the recommended widths and lengths for fixed and floating slips. The water acreage required for slip use is shown as the maximum number of boats per acre in Table 3-2. Alignment of the slips should be parallel to the current. Configuration of boat slips efficiency is achieved by use of single or double-wide slips with access from walkways attached to the shore. Walkways between rows of slips should be oriented perpendicular to the shoreline. Slips generally should be perpendicular to the main walkway. Designs that use curved walkways or curved slips are not efficient in use of water area, promote damage to boats, and are more expensive to build and maintain. If slips of different widths are off the same walkway, the slips should be arranged symmetrically by width on either side of the walkway to ensure symmetrical transmission of stresses to the walkway. Smaller slips should be placed closer to the shore. Double-wide slips can be used, saving money and water space and allowing more flexibility, but increasing the possibility of damage to boats by boat operators or wave action. Figure 3-4 shows a generalized layout of boat slips (Chamberlain 1983).

(b) Walkways. Walkways should be designed to be above the water level at all times and should be structurally sound and safe, kept free of mud, ice, snow, and grease. Walkways should be constructed perpendicular to the shoreline. Walkways less than 200 ft (61 m) long should be straight, while those greater than 200 ft (61 m) can jog or angle at the halfway point. This change

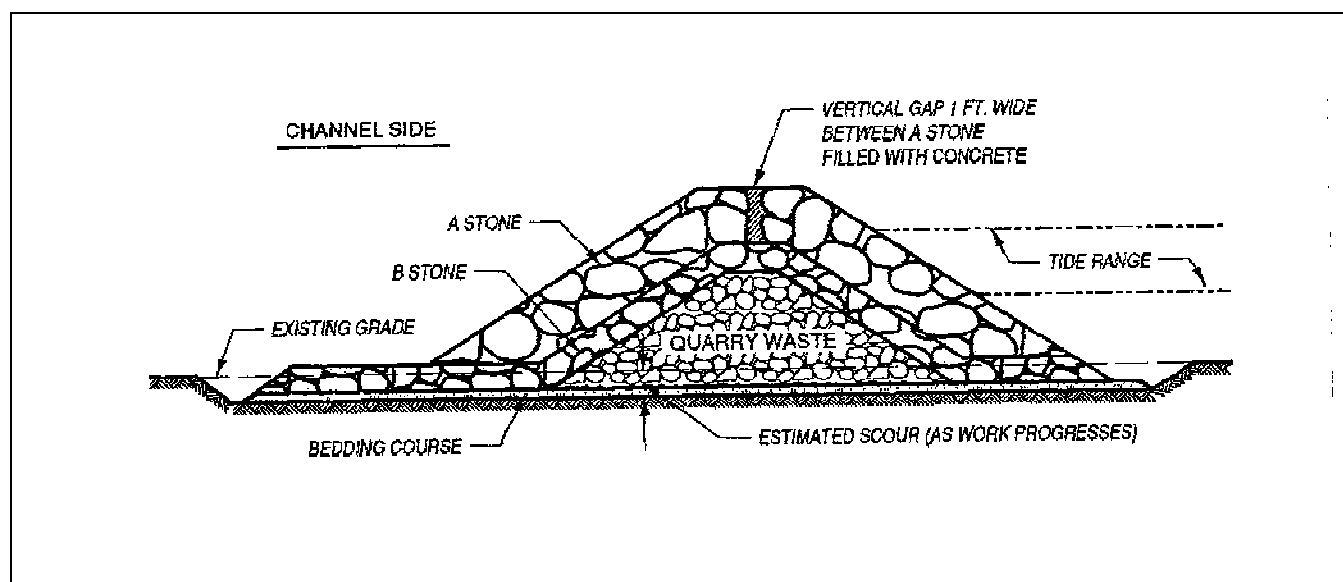


Figure 3-2. Typical cross section of a rubble-mound jetty

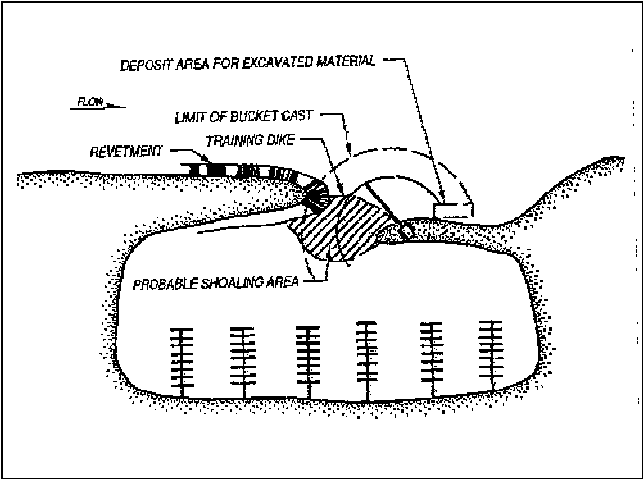


Figure 3-3. Maintenance of entrance to off-river marina basin with land-based equipment

Table 3-1 Recommended Slip Widths for Various Slip lengths		Slip Length									
		25	30	35	40	45	50	55	60	65	
Width, floating slips		10	11	12	14	15	17	18	18	19	
Width, fixed slips		11	12	14	16	18	19	19	20	22	

Table 3-2 Maximum Number of Boats Per Acre			
Fairway Width Boat Length (L)	Floating Slips 1.25 X L	Floating Slips 1.5 X L	Fixed Slips 1.5 X L
25	90	87	93
30	69	66	72
35	50	47	52
40	38	37	41
45	32	31	32
50	26	25	27
55	21	21	25
60	20	19	22
65+	17	16	18

improves lateral stability and modifies the impression of a long pier. Curved or star arrangements for walkways are wasteful of water space, conducive to boat damage, and are expensive to build and maintain. For floating walkways, the finger walkways should extend the full boat length. The finger walkways should not be less than 3 ft wide. A "T" should be placed at the end of a walkway for lateral stability of the pier, and should be at least as long as the slips on either side of the main walkway.

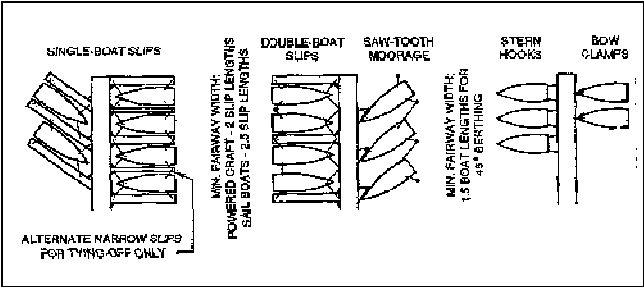


Figure 3-4. Small-craft berthing system (Sembler et al 1969)

Main walkway widths should be a minimum of 4 ft wide. If vehicles such as golf carts are anticipated, a minimum width of 8 ft (2.4 m) should be allowed for turning. Additionally, if significant pedestrian traffic is expected, the width should be at least 8 ft (2.4 m). Finger walkways may need widths greater than 3 ft (0.9 m) for stability (floating) or for strength and rigidity. Finger walkways do not have to extend the length of the slip (Chamberlain 1983, National Water Safety Congress 1988).

(c) Moorings. Mooring piles at the outmost end of the slip allow stern-to-bow mooring (Figure 3-5). For slips longer than about 25 ft (7.6 m), an additional mooring pile should be placed about halfway down the length of the slip. This additional pile, called a spring pile, helps restrain the fore and aft motion and provides protection between boats of adjacent slips. Additionally, a spring pile can be substituted for every other finger walkway (Chamberlain 1983).

(d) Fairway. The width of the area between adjacent rows of slips, i.e., the fairway, should be 1.5 times the length of the longest slip. If the current parallel to the long dimension of the slip exceeds 2 to 3 knots, even temporarily, the fairway should be widened to 1.75 to 2.00 times the length of the longest slip to allow for maneuvering in the down current (Chamberlain 1983).

(e) Basin shape. Natural basins are often used for marina development, taking advantage of natural protection for boat slips. In some cases, it is necessary to construct a basin for protection from waves or high water levels. Surrounding the mooring area with a breakwater or other protection will provide the necessary protection. Marina basins should be rectangular in shape to utilize space and for design purposes, the shorter side should be a multiple of 200 to 250 ft (61 to 76.3 m). The use of vertical bulkhead walls should be minimized and interior

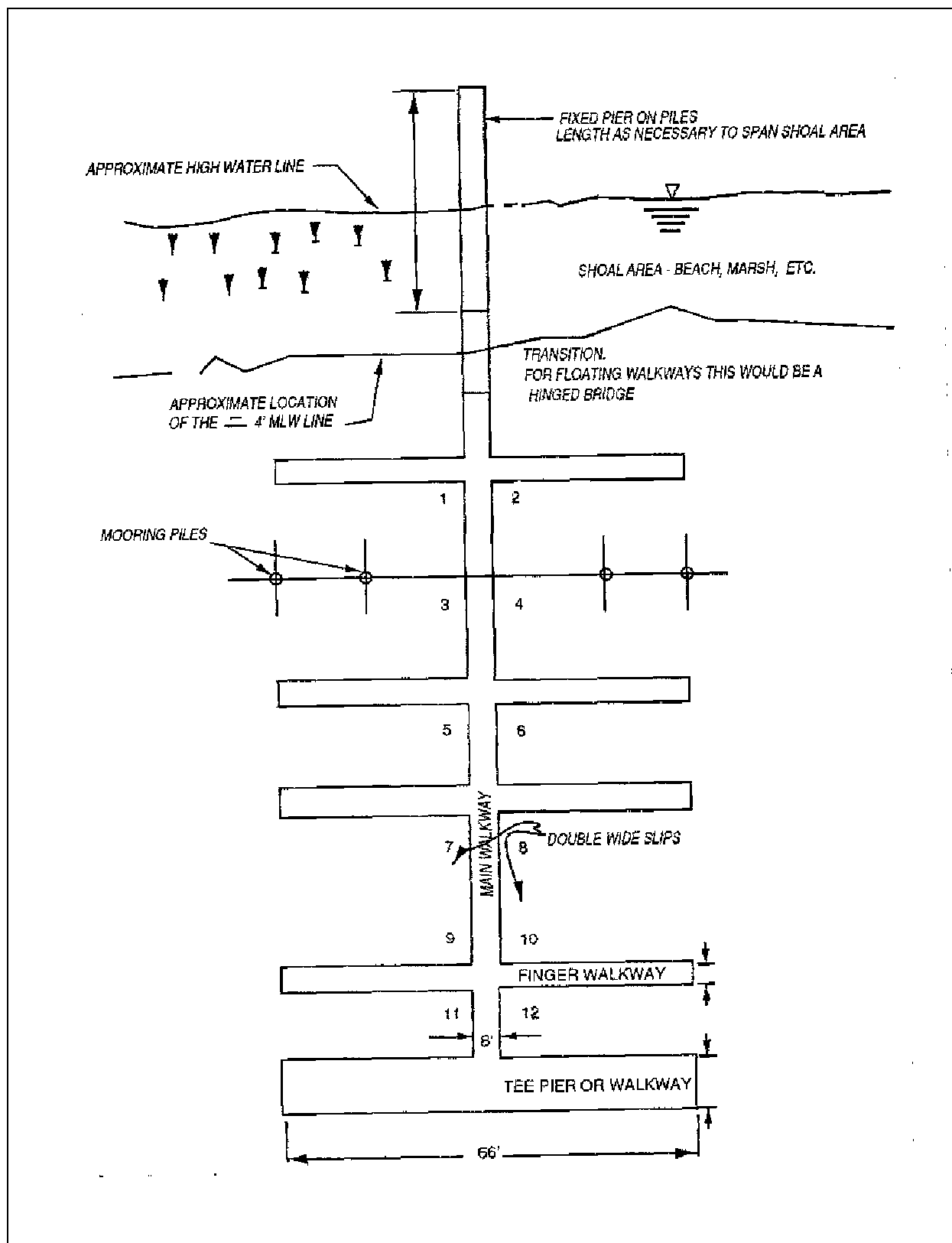


Figure 3-5. Basic layout for marina walkways (Chamberlain 1983)

corners should be gently rounded, preferably with constantly changing radii. Such designs result in the most efficient use of water area and promote water circulation. The basin bottom should be sloped toward the exit and the waterway outside the marina. In designing a basin, concern should be given to preserving or encouraging all natural flushing activities. If necessary, artificial flushing should be considered (Chamberlain 1983).

(f) Channels. Channel entrances and the channel leading to a marina should be as large as possible so as to provide safety and ease of passage in times of storm, fire, or other emergency, and to promote flushing. Where possible, the entrance should be located to avoid the direct entry of waves. Any bends that are necessary should be gradual (Dunham and Finn 1974). A breakwater can be constructed to protect channel entrances from the direct entry of waves (Chamberlain 1983).

(g) Harbor entrance channel. Harbor entrance channels should be at least 60 ft (18.3 m) wide or four times the beam of the widest boat berthed in the marina.

(h) Channel leading to the marina. A clear width of twice the entrance channel width, but not less than 60 ft (18.3 m), should be required.

(i) Channel turning. Required widths for turning are 2.25 times the length of the longest boat. For sites with frequent onshore winds or a large number of single screw power boats, the allowance for turning width should be increased from 2.5 to 2.75 times the longest boat.

e. Dead-end canal.

(1) General. Small boat dead-end canals are generally constructed for access to residences with docking facilities. Construction typically consists of excavation of an access channel through wetlands by widening an existing creek or excavating a totally new watercourse. The access channel provides easy access to the ocean, coastal waterway, river, reservoirs, or lake. Perimeter canals are often connected to the access canals to increase the density of home sites. Christensen and Snyder (1978) provide classification of existing canal systems; most canal systems in the classification terminated in dead ends.

(2) Environmental impact. The major environmental impact of early canal design was loss of wetlands. The dead-end configurations inhibited mixing and exchange of canal waters with the parent water body. As a

consequence, storm-water pollutants and domestic wastes accumulated in the canals, resulting in nuisance plant growth and depressed dissolved oxygen. Because of the resulting environmental degradation, most regulatory agencies prohibit the construction of new residential canals until it can be shown that such systems are compatible with the site, that the environment will not be degraded, and that all regulatory criteria are met. Several techniques have recently been developed for reestablishment of wetlands and sea grasses that can be used to mitigate for habitat losses and create new habitat. These techniques are discussed in EM 1110-2-1204 and EM 1110-2-5026.

(3) New canal design. New canal design recommendations that are less damaging to the environment have been suggested (USEPA 1975, Morris 1981, U.S. Army Corps of Engineers 1983):

(a) Canal developments should be restricted to non-wetland areas.

(b) Flow-through or indented boat slip designs are preferable to dead-end canals due to their superior circulation characteristics. To the extent possible, dead-end features should be eliminated from canal systems.

(c) Canal depths for shallow draft pleasure craft should be no more than 4-6 ft below mean low water. It has been observed that "deep" canals are not adequately flushed by tidal action and that lower layers act as a trap for sediments and organic material. It has also been observed that canals that are very shallow (under 4 ft) may have poor flushing characteristics, poor navigability, and increased turbidity due to boat traffic.

(d) The grade of the canal bottom should be such that no sills are created at any point in the system. When a canal is first dredged, before connection to the receiving water body, a plug is often left in place. Upon removal, a sill may remain which impedes the circulation of the bottom waters.

(e) Canals should be designed to maximize wind-induced mixing, i.e., maximum width, minimum length, and orientation with prevailing winds.

(f) Canal design should contain some shallows. Intertidal and littoral vegetation consume nutrients from the water; thus, the canal may improve the quality of the receiving waters by reducing nutrient content and possibly raising the level of dissolved oxygen.

(g) Surface drainage patterns should be designed with swales, contours, and shallow depressions for water retention, to minimize direct runoff into canal waterways.

(h) For residential sewage treatment, package plants or lagoon systems are recommended.

f. Launching ramps.

(1) General. If properly placed and designed, launching ramps should have a minimal impact on aquatic and terrestrial resources. Under some conditions there may be concern over the effects of wave wash on bank stability and vegetation. If adjacent areas are shallow, bottom-dwelling organisms and their habitat can be disrupted if boats run aground or scrape the substrate. Valuable habitats and their biota may be protected if well-marked routes to the launching ramp are established and recreational craft are kept away from sensitive areas. If ramps have to be located near valuable areas, breakwaters, bank protection devices, or speed warnings may be required.

(2) Ramp design. Direct access to water areas should be prevented by designing boat launching ramps that require a deliberate turn from any access roads. Boat ramp designs vary depending upon their usage (U.S. Fish and Wildlife Service 1980). Ramps are usually constructed adjacent to deep water for easy launching of boats on trailers. They may range in widths from 10 ft to over 50 ft (3-15 m). The length of a ramp may be over 60 ft (18 m). The slope should be between 12 and 16 percent above the waterline and 15 to 20 percent below the waterline (EM 1110-1-400, National Water Safety Congress 1988). It is recommended that a ramp be paved to about 5 ft (1.5 m) below the extreme low tide. There should also be a level, gravel shelf at the end of the ramp. The most common construction technique for a ramp is to use a gravel foundation covered by 3 to 6 in. of concrete. Piers should also be provided for boarding and holding a boat while launching. It is recommended that piers be provided on both sides of the ramp. The ramp should be placed in a well-protected area with minimal currents, but one that is well flushed to avoid the buildup of exhaust, petrochemicals, and other pollutants associated with boating operations. The ramp should have a washdown facility. Oil, grease, and other pollutants washed off a boat should be discharged into the sewer system rather than into the boat basin.

(a) Ramp safety designs. To provide adequate traction, the surfaces of the ramp should be scored or patterned. Deep grooves in the concrete should be perpendicular to the slope of the ramp to provide good

vehicular traction. Where drop-offs exist or could form, retaining curbs should be incorporated at the lower end of the ramp and on the outside edges or ramps. Consideration should be given to providing chock blocks, where feasible. Operation plans should include plans to keep ramps free of algae growth and siltation (National Water Safety Congress 1988).

(b) Ramp area design. For boat trailer parking, a general rule is 25 car and trailer parking spaces per lane, except where demand or site conditions require deviations. A minimum of one 75-ft- (23-m-) diam vehicular turn-around should be provided for each ramp. Courtesy loading docks should be provided to allow for safe loading and unloading of persons and gear (EM 1110-1-400, National Water Safety Congress 1988).

(c) Security lighting. Adequate security lighting should be provided. Appropriate signs should be placed to encourage safe boating practices. Overhead power lines crossing the water should be posted (National Water Safety Congress 1988).

(3) Environmental impacts.

(a) If not properly designed, the construction of a boat ramp and associated parking facilities can result in both immediate and long-term environmental effects. Construction of a ramp and parking facilities can cause increased erosion and associated turbidity as a result of altering the shoreline and intertidal habitats, smothering of benthic animals, and release of toxic substances used in the construction material. A possible solution is the planting of marsh grasses and sea grasses (EM 1110-2-1204 and EM 1110-2-5026). Ramp site selection should avoid, if possible, wetlands, and highly productive intertidal habitats (i.e., shellfish beds, sea grasses, nursery habitat, etc). The construction of a ramp will displace shoreline and aquatic habitats and in most cases replace it with less productive habitat, particularly if the ramp is heavily used. Construction can also result in increased noise and air pollution.

(b) Long-term impacts are associated with dredging and channel deepening to accommodate the ramp, protective structures that may be required, parking facilities that require clearing and grading the land, and increased human usage of the area. Increased operation of boats in association with the ramp will increase turbulence of the water, petrochemical pollution, and noise which may affect fish and wildlife resources and humans in the area. Generally, channel depths providing a clearance of 2-3 ft between the propeller of a vessel and the channel bottom

during low waters, will be sufficient to prevent increased turbidities (NOAA 1976). It is also possible that a greater number of boats and their wakes may increase shoreline erosion, requiring additional protective shoreline structures. If the ramp becomes a popular boat launching area, it may attract other commercial facilities that could further increase habitat alterations.

(4) Alternatives.

(a) An alternative that should be considered in place of a boat ramp is a hoist that can pick a boat up off a trailer and place it in the water. A hoist usually requires a pier or other structure to allow access to navigable waters. The hoist would be appropriate where the water is deep close to the shore. In areas where there is a narrow band of marsh or shallow water separating the shore from deep water, a dock or pier could be used to span these areas.

(b) A marine way (dolly) is another alternative to a boat ramp. This operation requires lifting the boat onto a rail and lowering the boat down the rail into the water. Its advantage is that boats can be launched in areas with a shallow slope at low tides.

3-2. Basin Operating Criteria

a. Periods of Operation.

(1) Under certain conditions, it is often possible to restrict dredging, construction, or related activities to appropriate times of the year so as not to negatively affect certain biota (LaSalle 1988, Sanders and Killgore 1989). Boat ramps are usually constructed during low water periods when banks are dry and construction will not be impeded by high water. There are probably fewer negative effects to aquatic biota during late summer and fall when aquatic plants have senesced, reproduction of fishes and macroinvertebrates has taken place, and many aquatic insects have emerged. Water clarity is usually highest during late summer and early fall, so the effects of sedimentation may appear great, although impacts to spawning or nursery areas will be minimal.

(2) It may be virtually impossible to restrict access to boat ramps during selected times of the year. When fish spawning and plant growth are maximal (i.e., during the spring), recreation use is often at a peak. Rather than attempt to restrict access, boat ramps and facilities should be designed so that sensitive areas will not be damaged. The use of buoys and breakwaters, placing boat lanes so that they are straight and do not encroach on valuable

areas, and enforcement of reduced speed zones are all methods of protecting biota regardless of season. Seasonal restrictions on dredging and construction activities are based on perception or concern that such activities will have a negative impact on biological resources. The major concerns are related to impacts on migrating waterfowl, shore and wading birds, fish migration, and larval and juvenile fish and shellfish. Restrictions may be justified in cases where there are known occurrences of the animals in the vicinity of the construction site during specific seasons. Project activities should be scheduled to minimize interference with reproduction, rearing, and migration of these biological resources (Cardwell and Koons 1981). Careful planning and scheduling of dredging and construction can minimize these impacts.

b. Water quality impacts.

(1) Flushing. Water quality impacts of small boat basins can be attributed to excess input of pollutants and/or inhibited flushing. Flushing is a concept of how long a constituent remains in the water body. The term "flushing" is often misused in that a single number (e.g., 10 days) is sometimes used to describe the flushing time of a harbor. In actuality, the flushing rate ranges from 0 days at the boundary to several weeks depending on location within the marina water body. A decrease in flushing increases the time that a constituent exerts its influence on the water quality. Site selection, basin design, and operation procedures are the most effective ways to minimize possible water quality impacts. Objectives should include minimization of pollution sources and maximization of flushing. Evaluation of water quality impacts involves an assessment of the input of pollutants and flushing of the water body.

(2) Pollutant sources. The term pollutant refers to either naturally occurring or synthetic materials that may occur in sufficient quantity to adversely affect water quality. The major sources of pollution include storm water runoff, sanitary wastes, and wastes from boat operation and maintenance. In addition, pollutants may be introduced through dredging and dredged material disposal during either construction or maintenance.

(a) Rainfall creates runoff from roofs, parking lots, roads, fields, forests, lawns, etc. The runoff may carry a variety of pollutants that may degrade water quality. These pollutants include sediment, nutrients, pesticides, oil and grease, metals, and pathogens.

(b) Sanitary wastes cause an increase in the nutrient supply, an increase in biochemical oxygen demand, and

introduction of disease-causing viral and bacterial organisms. Pollutants from this source can enter small boat basins in wastewater directly discharged from boats or from improperly functioning or poorly located septic systems that allow sewage effluents to leach into the basin.

(c) Other wastes from boat operation and maintenance include pollutants such as gasoline, oil, and grease; solid waste; trash; lead; copper; and detergents.

(3) Predictive techniques. Application of predictive techniques to assess the water quality impacts (e.g., depressed dissolved oxygen (DO)) of these pollutants requires an estimate of pollutant loading. If actual values for various loadings are not available, the USEPA (1985) provides estimates of constituent concentrations for urban runoff and contribution from boats.

(4) Flushing and DO. The water quality in harbors is generally lower than the water quality of the parent water body. However, successful control of water quality is usually dependent upon periodic exchanges of harbor water with the parent water body. Dunham and Finn (1974) suggested that for single entrance marine harbors, an average daily exchange of water equivalent to about one-third of the harbor's mean tidal volume is usually sufficient to prevent water stagnation. Boozer (1979) stated that for marine harbors, turnover times of 2-4 days will generally prevent stagnation or the buildup of high pollution concentrations. By correlating hydraulic model estimates of flushing with water quality measurements in five Puget Sound Marinas, Cardwell, Nece, and Richey (1980) suggest that a mean exchange coefficient of 30 percent was necessary to prevent serious fluctuations in DO. The mean exchange coefficient is the percentage of water in a basin that is removed and replaced with ambient water during each tidal cycle. Although the three methods use different techniques, the results are nearly equivalent. Importantly, the three exchange estimates are for marinas for which tidal action is the dominant factor.

(a) Rivers and lakes. In flowing rivers, potential water quality problems are minimized because the river currents will induce circulatory flow. In lakes, small craft harbors are typically constructed in coves; the use of floating docks minimally affects the existing circulation and thus the exchange with the parent water body.

(b) Marinas. Marinas may be located near the ocean where solid breakwaters may be used for protection. The harbor construction may significantly affect the water exchange with the parent water body. Nece et al. (1979)

used physical models to study geometric effects of marina design and suggested design features for maximum flushing: the best design of a rectangular basin for optimal tidal flushing would have a length/breadth ratio between 0.5 and 2.0, rounded corners, and a centered entrance. However, asymmetric basins within the same length/breadth ratio and with rounded corners also exhibit adequate flushing characteristics. Little guidance was found on designs with multiple entrances; however, parent water body circulation could be used to enhance water exchange. Two openings at opposite ends of the marina could establish flow-through water currents. Other design considerations for enhancing flushing include (Boozer 1979): marinas should have wide and deep entrances with depth gradually decreasing toward the inner reaches of the marina; marinas should never be deeper than either the open water or channels to which they are connected and never deeper than their own access channels; and marinas should use floating breakwaters to dampen incoming waves yet allow less restricted water circulation. Most of the early designs of marina systems were based on a simple flushing analysis. The flushing analyses were a variant of the tidal prism method (Walton 1983). Such an approach for marinas is a reasonable "back-of-the-envelope" calculation to obtain an idea of the exchange of water between the marina and adjacent waterway. The procedure is described in Chapter 4 of the *Coastal Marinas Assessment Handbook* (USEPA 1985). In studying South Beach Marina in Oregon, Callaway (1981) used a simple flushing model to simulate mixing. His results showed excellent agreement with a physical model of the system, but showed that both the physical and flushing models overestimated the flushing time when compared to field data.

(c) Residential canals. Tidal prism analysis is not applicable to canal systems because the assumption of complete mixing is not valid. The use of the one-dimensional model DYNTRAN (Moore and Walton 1984) provides a relatively rapid, conservative, and inexpensive procedure for assessing flushing and DO. The procedure is conservative because the physical mixing processes due to wind, density-induced currents, and secondary currents are not included in the model. Several basin design features that promote flushing are basin depths that are not deeper than the open water, two openings at opposite ends of the marina to establish flow-through currents, minimal vertical walls, a rectangular basin with single entrances that are centered, and basin depths that gradually increase toward open water.

(5) DO analysis. The level of DO is used to characterize water quality because it serves as an integrated

measure of physical, chemical, and biological processes. DO is included in all state water quality standards. The procedure for DO analysis consists of two phases. The first phase consists of a flushing analysis for estimates of flushing rates or flows. The second phase consists of the use of the flushing rate estimates for the solution of mass balance equations relating DO to sources such as reaeration and sinks such as biochemical oxygen demand (BOD) decay. A procedure is outlined in the Coastal Marinas Assessment Handbook (USEPA 1985). Two- and three-dimensional numerical hydrodynamic and water quality models are available (Hall, Dortch, and Bird 1988) that can address the flushing and water quality of small boat basins. Although not justified in the past, due to the rapid decrease in computational costs and the capability to run some applications on microcomputers, the application of numerical models for analyses of small boat basins is now feasible.

(6) Water exchange. Water exchange does not always ensure good water quality. A significant factor in water quality control is the elimination of direct sources of pollution: storm-water runoff, sanitary wastes, and wastes from boat operation and maintenance.

c. Control of adjacent land and water use. Planning for adjacent land and water use should be documented in a master plan and in provisions of permits for marinas. The master plan should consider trash and garbage pickup, and provision of a boat maintenance area for washing boats. The need for maintenance dredging to minimize siltation and to ensure adequate channel depth and alignment should be evaluated. Maintenance dredging should be scheduled to minimize impacts on current paths and wave action and impacts to adjacent beaches and wetlands (Chamberlain 1983).